

## Lamp Flicker Predicted by Gain-Factor Measurements

**Background** Different brands of incandescent bulbs rated at the same wattage and voltage respond almost identically to voltage fluctuations. However, the response of comparable fluorescent lamps to voltage fluctuations can vary quite significantly from brand to brand and model to model. Therefore, published standards that limit voltage fluctuations, which are based solely on human perception of light flicker from incandescent bulbs, are not valid for most modern lighting products.

Consumers concerned about flicker would no doubt appreciate a rating system that specifies the flicker performance of lighting products. However, determining the flicker performance of each product through human-response testing is likely to be impractical. Moreover, perception of light flicker varies significantly among different people, which makes statistically valid results from human response testing difficult to obtain. An alternative to determining flicker performance based upon the human eye-brain response is to measure the gain factor of lighting products with electronic instruments, which can be done much more quickly and economically. Gain factor, which is defined in International Electrotechnical Commission (IEC) Standard 1000-4-15, may be a good indicator of lamp flicker performance for incandescent lamps. In PQTN Brief No. 23, measured gain factors were used to compare the flicker performance of various fluorescent lighting products. To confirm the accuracy of gain factor as a predictor of human perception of flicker, gain factors must be compared to human perceptions.

**Objective** The objective of the tests performed at the Electric Power Research Institute (EPRI) was to determine whether lamp gain-factor measurements can be used to reliably predict the human perception of flicker from a variety of modern lighting products.

**Test Setup** Eight observers participated in the tests. During each trial, the observer sat facing a white, untextured posterboard two feet from the observer's head. Each participant observed each of the following six lamps during the flicker tests: two four-foot florescent fixtures with two-lamp electronic ballasts, two compact fluorescent lamps (CFLs) with magnetic ballasts, one CFL with an electronic ballast, and a 60-watt incandescent bulb, which was tested as a reference. The tested lamps were selected from 55 different previously tested lamps based upon their measured gain factors. Lamps with a screw base were placed in a fixture surrounded by an aluminum reflector to block direct light from the observer's eyes. The four-foot lamp fixtures were suspended nine feet above the floor. Before each trial, the lamps were kept warm by operating them outside the test booth. Arbitrary-wave generators and a power amplifier supplied 60-Hz, 120-volt power to the lamp under test. During each trial, the observer was instructed to look at the posterboard. To create flicker, the ballast input voltage was modulated with a 10-Hz and then a 20-Hz square wave that was slowly reduced in amplitude from 2.5% of the supply voltage until the observer verbally signaled that the flicker had stopped. At that point, the amplitude of the square wave was recorded as the observer's flicker perception for a particular lamp. These voltage amplitudes were then normalized based upon the observer's perception of flicker from an incandescent bulb (that is, the flicker perception for an incandescent bulb is one). Figure 1 shows the test setup.

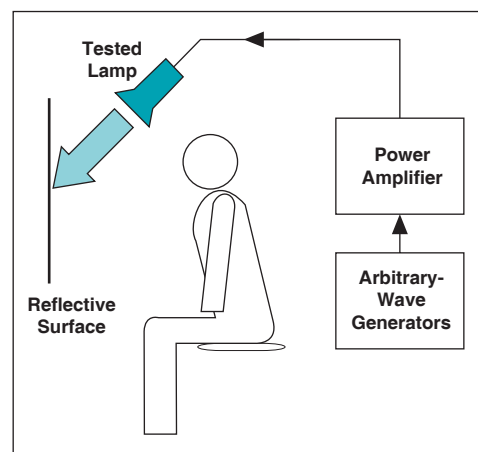


Figure 1. Test Setup

## Test Results

Tables 1 and 2 (next page) show the test results at 10 and 20 Hz. The flicker rankings of each observer were determined by comparing the perception results for one lamp to the perception results for the other five lamps (a higher rank means more perceived flicker). When an observer had identical perception for two lamps, the ranking value of the two lamps was averaged.

At 10 Hz, seven of the eight observers agreed that CFL1, which had the lowest gain factor, produced the least flicker of all the lamps observed. The eighth observer ranked CFL1 as the second least producer of flicker. According to six of the eight observers, at 10 Hz, the incandescent bulb, which had the highest gain factor, produced the highest or second highest amount of flicker. The other two observers ranked the

Table 1. Test Results at 10 Hz

Rank by Observer (Higher Numbers Mean More Perceived Flicker)						
Subject	CFL1	4-FT1	CFL2	4-FT2	CFL3	Inc.
S1	1	5	6	2	3	4
S2	1	3	5	2	4	6
S3	1	2	4	5.5	3	5.5
S4	1	3	4	5	2	6
S5	1	4	3	6	2	5
S6	1	3	6	4	2	5
S7	2	5	6	3	1	4
S8	1	2	6	4.5	3	4.5

Average Normalized Flicker Perception (Higher Numbers Mean More Flicker)						
0.44	0.76	1.02	0.87	0.66	1.00	

Normalized Lamp Gain Factors						
0.32	0.44	0.62	0.72	0.73	1.00	

Uses electronic ballast.

Table 2. Test Results at 20 Hz

Rank by Observer (Higher Numbers Mean More Perceived Flicker)						
Subject	CFL1	4-FT1	Inc.	4-FT2	CFL2	CFL3
S1	1	4	3	5	6	2
S2	1	3	2	4	6	5
S3	1	3	2	5	6	4
S4	1	2	3	5	6	4
S5	1	2	4	6	3	5
S6	1	3	2	4	6	5
S7	3	1	2	6	5	4
S8	1	5	2.5	4	6	2.5

Average Normalized Flicker Perception (Higher Numbers Mean More Flicker)						
0.76	1.12	1.00	1.61	1.91	1.24	

Normalized Lamp Gain Factors						
0.58	0.79	1.00	1.05	1.19	1.40	

incandescent bulb as fourth highest of the six lamps observed. At 20 Hz, extremes in gain factor also correlated to the perception of the observers, even though the flicker characteristics of the incandescent lamp changed with the frequency. That is, the incandescent lamp had a significantly lower gain factor at 20 Hz, while the fluorescent lamps had about the same gain factor. Figure 2 compares the normalized perception (average and range) and the normalized gain-factor measurement for each lamp.

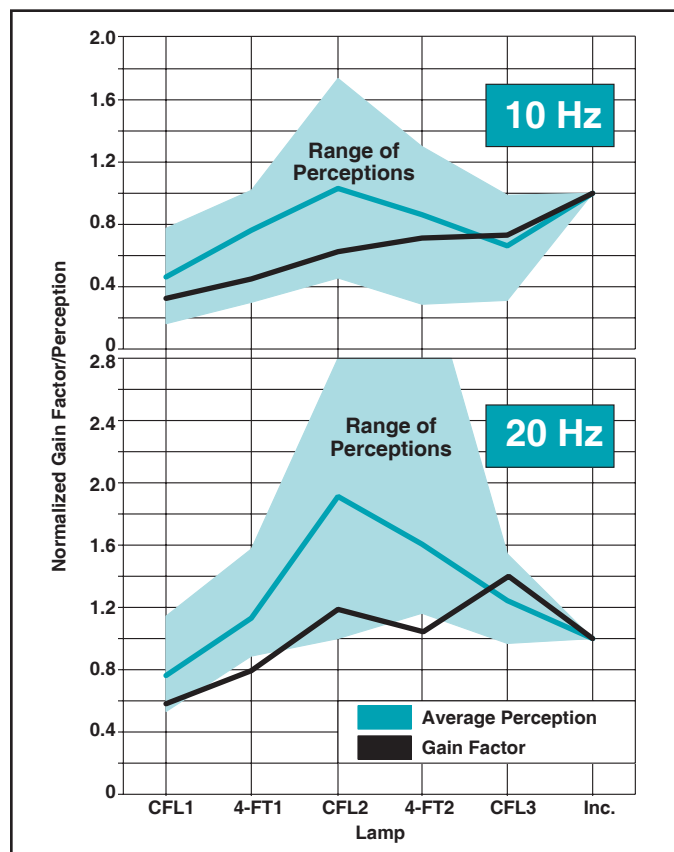


Figure 2. Normalized Gain Factors, Normalized Perceptions, and Ranges of Perceptions at 10 and 20 Hz

## DISCUSSION

The test results indicate a fairly good correlation between gain factor measurement and individual human perception of light flicker. For instance, whereas six of the eight subjects ranked the incandescent bulb highest or next to highest in perceptible flicker at 10 Hz, seven of the eight ranked it as only second or third highest at 20 Hz, a change in perceptible flicker accurately predicted by gain factor measurements. However, there was less agreement among the observers on the ranking of the lamps between the extremes, and perceptions varied widely. At both 10 and 20 Hz, the gain factors for CFL-3 predicted more flicker than the subjects of the tests perceived. During previous testing (1992), this same lamp had a high level of light noise, a variation in light output similar to ripple in a dc voltage. This light noise, which was filtered out during gain-factor measurements, may have been the reason why the perceived flicker of CFL-3 was lower than predicted. However, this interaction is not adequately understood.

## SIGNIFICANCE

The gain factor of a lamp, as defined in IEC 1000-4-15, can be used to develop a rating system for flicker performance of lighting products. Such a rating system will enable manufacturers to identify the flicker performance of a lamp, or a combination of lamp and ballast, and will enable consumers to select lighting products based upon their flicker characteristics. Additionally, the rating system will engender an awareness about flicker and perhaps encourage manufacturers to design lighting products that produce little or no flicker. Thus end users will ultimately benefit from nearly “flicker-free” lighting products.

## ACKNOWLEDGMENTS

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**TUTORIAL: The Factors of Lamp Flicker**

The gain factor of a particular lamp indicates how much its light output will change during voltage fluctuations. The type of lamp—incandescent or fluorescent, magnetic or electronic, and so on—is the main determinant of gain factor. However, **thermal inertia**, the tendency of a filament or gaseous arc to retain a steady level of illumination during voltage changes, determines how quickly a lamp responds to voltage fluctuations. Once the power has been removed from a lamp, the temperature of the filament or arc decays exponentially. The time it takes the light output to decay from nominal to 63 percent of nominal is equal to one time constant ( $t_c$ ). The filament in an incandescent bulb and the arc in a fluorescent lamp both have thermal inertia, and the mass of the filament or arc determines the amount of thermal inertia. The larger the mass, the greater the thermal inertia. For example, because of its thinner filament, a 230-volt incandescent bulb—which is typically used in Europe—has less thermal inertia (a  $t_c$  of about 19 milliseconds) than a 120-volt bulb of the same wattage (a  $t_c$  of about 28 milliseconds). Consequently, a 230-volt bulb will flicker more during 10-Hz voltage fluctuations than the 120-volt bulb. In contrast, the arc of a fluorescent lamp has very little thermal inertia (a  $t_c$  of about five milliseconds for a typical magnetically ballasted fluorescent lamp). Therefore, the gain of a fluorescent lighting product remains the same throughout the visible range of voltage fluctuations (from 0 to 50 Hz). For an incandescent lamp, the effect of thermal inertia increases as the frequency of voltage fluctuations increases. For example, 10-Hz voltage fluctuations produce less than half the flicker in a 120-volt, 60-watt incandescent bulb than 1-Hz fluctuations.

Just as the inherent features of lamps—such as lamp type and thermal inertia—can affect gain factor, so can certain conditions of the power supply. For example, the applied **steady-state ac-voltage level** affects the flicker of incandescent lamps, as well as some fluorescent lamps. Lamp flicker decreases as the steady-state lamp voltage decreases. For instance, a five percent decrease in RMS voltage (120 volts to 114 volts) will cause a ten percent decrease in lamp gain factor (3.1 to 2.8). However, decreas-

ing the steady-state voltage using a typical incandescent lamp dimmer, which incorporates an SCR to control RMS voltage to the lamp, will produce the opposite effect. Most of these dimmers do not reduce flicker-causing voltage fluctuations proportionally to the reduction in RMS voltage. The net effect is an amplification of perceived flicker, an increase in gain by as much as two times with some types of SCR dimmers and a negligible increase with others (see PQTN Brief No. 23).

The **ac-voltage waveform** also affects lamp flicker in arc lamps such as the typical fluorescent lamp. Documented case studies and laboratory research indicate that the flicker from magnetically ballasted fluorescent lamps can increase when the angle of the arc ignition fluctuates. These fluctuations, called “ignition angle jitters,” are usually caused by continuous changes in the voltage harmonic distortion. Ignition angle jitter can occur when the frequency of voltage fluctuations is close to but not a whole-integer harmonic of 60 Hz (for example, 187-Hz voltage fluctuations cause lamps to flicker at 7 Hz). In an incandescent lamp, changes in the voltage waveform will not affect flicker if the RMS voltage is relatively constant.

Because the steady-state ac-voltage level and waveform are known factors of lamp flicker, they can be controlled during gain-factor tests and should not affect the validity of gain-factor measurements as a predictor of lamp flicker performance.